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Electrofishing Effort Requirements for Assessing Species Richness and Biotic Integrity in Western Oregon Streams

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Abstract.—We examined the sampling effort required in wadeable western Oregon streams at base flow to estimate fish species richness, percent abundance, and biotic integrity when employing three persons and one backpack electrofisher. Reaches were oversampled longitudinally and data were recorded separately for each habitat unit, allowing us to treat each habitat unit separately during data analyses. The median values of species richness from Monte Carlo simulations of the data indicated that a stream reach 40 times its mean wetted width was adequate to estimate 90% of species richness (i.e., all common species) in western Oregon fish assemblages. A reach length of 40 wetted channel widths was also adequate to precisely score an index of biotic integrity developed for western Oregon. However, where 40 channel widths are less than 150 m, we recommend a minimum distance of 150 m to ensure that sufficient numbers of individuals are captured, rare habitats are encountered, and riparian conditions do not fully determine channel morphology. In addition, at four sites we compared a rapid (4-h), one-pass sampling protocol of reaches 40 channel widths in length with an intensive, three-pass electrofishing protocol lasting more than 10 h. The rapid protocol occasionally underestimated species richness by missing vagile, cryptic, or rare species, but it usually estimated species richness, percent abundance, and the IBI as well as the intensive protocol. The rapid protocol and quantitative fish population estimates tracked the same trends in population size at one site for 5 years.

Scientists collect fish assemblage data to study fish distribution (Rahel and Hubert 1991), evaluate community structure (Grossman et al. 1982), and assess stream biotic integrity (Karr et al. 1986; Gurtz 1994; Hughes et al. 2000). Inferences regarding a given fish assemblage are generally based on a sample of a particular area with a given amount of effort. However, the number of species collected increases as the sampled area increases (Rosenzweig 1995) and varies with biogeography, habitat, sampling method, sampling efficiency, and the behavior, rarity, and patchiness of the fish being sampled (Larimore 1961; Bayley and Dowling 1993; Angermeier and Smogor 1995; Paller 1995).

A length of stream (or reach) is sampled because streams habitat is heterogeneous and fish are not uniformly distributed among habitat types. Although some scientists define reaches based on geomorphic homogeneity (Frissell et al. 1986), others use multiples of the average wetted width of the stream channel as a scaler for reach dimensions (Kaufmann et al. 1999).

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In recent years, several persons have estimated adequate electrofishing distances for assessing fish assemblages in a stream reach. Karr et al. (1986) suggested sampling reaches of 11–15 stream widths to assess biotic integrity. Based on empirical observations, Lyons (1992) determined that a reach length of 5–49 channel widths was needed to approach the asymptote estimated from observed species richness. Paller (1995) estimated sampling distances of 35–158 channel widths for collecting all species, 28–114 channel widths for collecting species constituting at least 1% of total fish abundance, and 13–83 channel widths for collecting common species. The sampling distances needed to collect 90% of observed species ranged from 14 to 67 channel widths (Angermeier and Smogor 1995; Patton et al. 2000; Dauwalter and Pert, in press). Based on data from Angermeier and Smogor (1995) and Patton et al. (2000), Cao et al. (2001) estimated that 82–134 and 14–121 channel widths, respectively, be sampled to estimate true species richness. These distances are similar to the 85–100 channel widths reported by Hughes et al. (2002) for estimating the richness of common species in large rivers. The differing electrofishing gears (backpack, towed, bank, boat, and electric seine) among these studies probably account for some of this variation.

The index of biotic integrity (IBI; Karr et al. 1986) is based on a set of richness and guild metrics that together indicate fish assemblage condition, and it is increasingly being used to assess the ecological condition of water bodies (Miller et al. 1988; Simon 1998). These metrics (hereafter, IBI scores) depend on various estimates of taxonomic richness and percent total abundance, which vary with sampling effort (Angermeier and Karr 1986). We used percent abundance instead of relative abundance (i.e., rare, common, or abundant) because of the greater accuracy of the former and we used it instead of absolute abundance (estimated from mark–recapture or multiple-pass removal) because percent abundance yields comparable species percentages with markedly less sampling effort (Rahel 1990).

Sampling effort is a general term that includes the distance along a reach over which sampling occurs (sampling distance), the number of person-hours employed at a location (sampling intensity), the amount and type of gear used, and the temporal duration of the sampling. Increasing each aspect of sampling effort increases the quality of data generated, the quality of the conclusions drawn, and the sampling cost. Because labor costs compose most of sampling costs, sampling distance and intensity are of great interest to managers. Therefore, it is useful to evaluate the increases in information gained from increases in sampling distance and intensity.

In this study, our first objective (in 1992) was to determine the sampling distance required to adequately estimate species richness and percent abundance and compute an IBI over a set of stream reaches of widely different sizes in markedly different ecoregions. Like Angermeier and Smogor (1995) and Patton et al. (2000), our decision criteria were based on collecting 90% of species richness observed in 1 d of sampling. Our second objective (in 1993) was to compare rapid one-pass and intensive one- to three-pass protocols.

Methods

Our study was divided into two main components: a sampling distance study and a sampling intensity study. In the sampling distance study, we sampled 15 western Oregon stream reaches to construct species richness–effort curves and IBI–effort curves to determine adequate sampling distance. From the reach distance determined in the sampling distance study, we developed a rapid (half-day) protocol for sampling stream fish assemblages. In the sampling intensity study, we compared the results from the rapid protocol with those obtained from intensive three-pass sampling at four large reaches for 1 year and for 5 years at a long-term ecological research reach.

Study Area

We sampled wadeable reaches in the Willamette Valley and Cascade Mountain ecoregions of western Oregon. These two ecoregions contain streams with distinctly different gradients, substrates, and clarity. The channel gradients in the Willamette Valley reaches were under 1% with substrates dominated by sand and finer particles, whereas the gradients of the Cascade Mountain reaches were more than 3% with gravel, cobble, and boulder substrates. The Willamette Valley reaches were clear or turbid, depending on water source, with maximum pool depths of 0.1–1.3 m; the Cascade Mountain reaches were clear, with maximum pool depths of 0.3–1.9 m.

Sampling Distance Study

The sampling distance study was conducted in summer 1992. Sixteen stream segments were selected randomly (via dot-gridded mylar dropped on 1:100,000-scale U.S. Geological Survey maps)

TABLE 1.—Physical and sampling characteristics of 15 reaches of western Oregon streams that were included in the sampling distance study and 4 reaches included in the sampling intensity study. Total length sampled is the product of the number of channel widths sampled and the mean width of the channel.

Stream name	Reach code[a]	Number of habitat units	Mean width (m)	Channel widths sampled	Elevation (m)	Watershed area (km^2)
Distance study						
Beaver-Scio	LWV1	15	6.2	73	82	75.7
Muddy–Finley	LWV2	12	7.2	59	77	156
Camous	LWV3	8	3.8	69	85	26.6
Muddy-Coburg	LWV4	27	7.5	71	101	75.5
Beaver tributary	SWV1	7	2.2	71	133	5.4
Smallman	SWV2	19	6.4	53	99	0.3
Reese	SWV3	7	4.0	81	117	16.5
Pringle	SWV4	17	2.0	81	64	7.6
South Fork Crabtree	LCM1	19	6.4	71	363	14.6
North Fork Gate	LCM2	23	7.7	78	335	31.8
Ennis	LCM3	14	3.8	94	401	12.2
Lookout	LCM4	17	12.4	44	448	62.0
Black	SCM1	20	3.0	76	1,070	4.54
Mack	SCM2	17	4.0	48	768	5.72
Potts tributary	SCM3	8	2.9	71	543	1.85
Intensity study						
Beaver-Tyee	LWV21		4.8	40	72	60.4
Cox	LWV22		5.2	40	66	29.1
Soap	LWV23		5.1	40	100	26.1
Lookout	LCM4		12.4	44	448	62.0

[a] Codes indicate the size and location of each stream, with abbreviations as follows: L = large, S = small, WV = Willamette Valley, and CM = Cascade Mountain.

using a 2 × 2 design with ecoregion location (Cascade Mountain/Willamette Valley) and stream size (small/large) as the two strata (compare Herlihy et al. 1997). Small streams in this study were defined as first-order (Strahler 1957) on the study maps and had mean wetted widths of 1.6–6.4 m; large streams were second- or third-order and were 3.8–12.4 m wide (Table 1). We selected study reaches randomly so that our results would be representative of the entire population of streams and to provide an unbiased estimate of the natural variability in the streams of both ecoregions. Three of the 16 random reaches were dropped; two small Cascade Mountain reaches contained no fish, and one large Cascade Mountain reach was too remote for the amount of sampling required. We replaced these reaches with two handpicked Cascade Mountain reaches (SCM2 and LCM2), for a total of 15 study reaches.

In the field, the sample reach began at a randomly chosen point on the selected map segment and extended upstream for 44–94 channel widths (Table 1). We chose 70 channel widths as our goal but lengthened reaches to coincide with the ends of habitat units. Shorter reaches were used if a reach had become dry or (based on prior fish surveys) all species had been captured. A week prior to fish sampling, each reach was surveyed and the length, width, and depth of each habitat unit recorded. A habitat unit was defined by channel morphology, water surface slope, depth, and velocity patterns (Frissell et al. 1986), and the habitat unit classification of Bisson et al. (1982) was used in both ecoregions. Habitat unit lengths were expressed as multiples of the average wetted width of the stream channel.

In the sampling distance study, fish were sampled by two experienced people; one person operated a Smith-Root model 12 POW DC backpack electrofisher and the other netted fish. All reaches were fished at 700–1,000 V; Willamette Valley reaches required frequencies of 50–70 Hz, and most Cascade Mountain reaches were fished at 100 Hz. We used 6-mm-mesh block nets to separate each habitat unit and sampled in an upstream direction. Reach fishing times ranged from 45 min in small streams to over 14 h in the largest stream. Fish in each habitat unit were anesthetized with tricaine methanesulfonate (MS-222), identified to species, counted, and returned to the habitat unit

alive. Voucher specimens were collected to verify field identifications. Lamprey *Lampetra* spp. ammocoetes were identified to species after Richards et al. (1982). Age-0 trout *Oncorhynchus* spp. were not identified to species because they lacked reliable field characters. We analyzed age-0 salmonids and lampreys as separate species because they inhabit an ecological niche that is separate from that of adults (Moyle and Vondracek 1985) and because they may be considered separately in bioassessments (Miller et al. 1988).

Rapid One-Pass Protocol

Based on the aforementioned sampling assessment in 1992, we developed a rapid one-pass electrofishing protocol that sampled reaches 40 channel widths long and that took less than 4 h of total time and 5,500 s of electrofishing with a crew of two fishers and one processor (<8 person-hours). Before sampling, each reach was divided into 10 subreaches, each of which was four channel widths long. These subreaches differed in width and the number of habitat units and sometimes contained parts of habitat units. We calculated the area of each of the subreaches from width measurements taken at each interval. In large reaches that could not be completely sampled, we allocated the total fishing time (based on 5,500 s of button time on the electrofisher) in proportion to the surface area of each subreach (i.e., wider subreaches with greater areas were fished longer). We sampled carefully upstream, monitoring fishing time, but without using block nets. If the time allotted to a subreach ran out before the end of the subreach, we stopped and proceeded to the next subreach. If we judged that fish were being herded upstream, we continued until reaching a habitat unit that aided in capturing them. In small (<4-m-wide) reaches, at least 150 m were sampled to ensure that an adequate number of individuals were collected and to increase the probability of encountering rare habitats (such as deep scour pools). Unlike in large streams, where pools occur naturally every 5–7 channel widths as a function of hydraulics, in small streams pools occur largely as a result of riparian influences, such as the falling of a single limb or aggregation of leaf packs into the stream. In addition, a single large tree falling into a small stream channel can fill the channel and dictate stream character.

Sampling Intensity Study

As described in Herlihy et al. (1997), four random reaches were selected and sampled in summer 1993 using the rapid one-pass protocol described above. We selected three large Willamette Valley reaches and one large Cascade Mountain reach to evaluate the effect of increasing sampling intensity. At these four relatively species-rich reaches, sampling consisted of a rapid one-pass protocol followed a week later by intensive three-pass sampling. At the reach scale, we compared species richness, percent abundance, and the IBI generated from a rapid one-pass protocol to those from intensive one-pass and three-pass protocols. Each habitat unit was sampled with one rapid and three intensive electrofishing passes. In the three Willamette Valley reaches we sampled 40 channel widths upstream, block-netting each habitat unit (10–24 person-hours), and at the Cascade Mountain reach (Lookout Creek [LCM4]) we sampled individual habitat units with a crew of five divers and two electrofishers (120–350 person-hours).

Lookout Creek is a Long Term Ecological Research (LTER) reach from which data are often extrapolated (Minshall et al. 1983). Fish population abundances were intensively sampled by dive electrofishing for 200 m there every summer during the 1990s and calculated via three-pass removal (Seber and LeCren 1967). The LTER sample typically involved seven people working 10 h/d for 5 d, or a total of 350 person-hours. We also sampled Lookout Creek annually from 1992 to 1996 with the rapid one-pass protocol. These samples enabled us to compare the results of the rapid one-pass protocol with those of intensive three-pass sampling at a site over 5 years.

Data Analyses

Species accumulation curves.—We compared two ways of calculating species richness–sampling effort curves: original sample order and a Monte Carlo analysis. The simplest approach was to accumulate species richness from the individual habitat units in the order in which they were sampled. This approach yields one species accumulation curve (cumulative species richness versus length sampled) per reach. The sample order approach may be influenced by the starting point if the first one or two habitat units hold many more species than subsequent habitat units. We addressed this issue by running 500 simulations, randomizing the ordering of habitat units for each possible number of habitat unit composites (1 to the total number of habitat units) for each reach. For example, for a composite of 4 habitat units out of 20, we randomly picked 4 habitat units (without replacement) and calculated the total species richness and reach

length (expressed in multiples of channel width) for those 4 samples in the composite. This was done 500 times for every possible habitat unit composite size in the reach (1–20 in this case). Results from each habitat unit composite size were averaged for a reach (i.e., all $n = 1$ unit results were averaged, all $n = 2$ unit results were averaged, etc.). Because habitat units varied in length, the data were split into channel width classes (0–5, 6–10, 11–15, etc.) for graphical presentation, and mean richness was calculated for each channel width class in each reach. Means across sample reaches were plotted for the sample order curve, but box plots and medians were plotted for the Monte Carlo results. Like Paller (1995), we counted rare species (defined as those comprising <1% of observed individuals) because they greatly affected the distance needed to maximize species richness.

Estimating true fish species richness at a reach.—There are a wide variety of estimators in the literature that can be used to calculate the ''true'' species richness at a reach from multiple subsamples (Colwell and Coddington 1994). Treating the individual habitat unit data from the reach length study as subsamples, we used the EstimateS computer program (http://viceroy.eeb.uconn.edu/estimates) to calculate the second-order jackknife and Michaelis–Menten estimators of true species richness at each reach. We chose these two estimators because of their fundamentally different conceptual bases, that is, occurrence incidence of rare species versus curve fitting from all species.

Smith and van Belle's (1984) second-order jackknife estimator was calculated as

$$S_{\text{obs}} + Q_1(2m - 3) \div m - Q_2(m - 2)^2/[m(m - 1)],$$

where S_{obs} is the total number of species observed, Q_j is number of species that occur in j samples, and m is total number of samples. The Michaelis–Menten mean species accumulation curve (adapted from a common biochemical rate function) was calculated as

$$S_n(1 + n/n_{50})/(n/n_{50}),$$

where S_n is the number of species observed after sampling n units and n_{50} is the number of sampling units needed to detect 50% of true species richness.

Index of biotic integrity.—We determined how an index of biotic integrity (IBI) changed with increased sampling distance and intensity. Indexes of biotic integrity are commonly used in bioassessments and an IBI has already been developed specifically for fish in Willamette Valley streams (Hughes et al. 1998). The Willamette Valley IBI ranges from 0 to 100 and is based on summing seven richness metrics and six percentage metrics, each of which could be affected by sampling distance or intensity. We ran a Monte Carlo analysis identical to that done for the cumulative species richness curves except that we calculated an IBI score for each of the 500 random simulations for each habitat unit composite size at each reach. We also calculated IBI scores from the rapid one-pass and intensive three-pass data in the sampling intensity study to see how index scores varied with increasing sampling intensity.

Chi-square test.—We compared proportionate abundances between the rapid protocol and the intensive three-pass method by means of a chi-square test of independence (Sokal and Rohlf 1981) in which the rapid protocol estimates were observed values and the intensive estimates expected values. We also combined the rows (i.e., percentages of species) containing small expected values (for similar species) to increase the expected values, as suggested by Sokal and Rohlf (1981), and found no differences in the results. We did not test the differences in percent abundance when we caught fish in the rapid pass that we later missed in more intensive passes because a chi-square test of independence cannot be used when an observed value has no expected value.

Results

Sculpin *Cottus* spp., lamprey, and dace *Rhinichthys* spp. were common benthic genera. Redside shiner *Richardsonius balteatus* was the most common water column species in Willamette Valley streams, and cutthrout trout *Oncorhynchus clarki* was the dominant native salmonid in Cascade Mountain streams. Small Cascade Mountain streams contained few or no fish and never had more than adult and age-0 cutthroat trout.

Sampling Distance

Fish assemblages in the two ecoregions differed, but the observed and true values of species richness were similar. Willamette Valley reaches had more species than Cascade Mountain reaches (Table 2). Total species richness ranged from 2 (adult and age-0 cutthroat trout) in small Cascade Mountain reaches to 11 in a large Willamette Valley reach. There was also a wide range in the total

TABLE 2.—Characteristics of fish assemblages in study reaches. Small Cascade Mountain reaches contained only one species of trout, with age-0 fish representing the second ecological species.

Reach	Number of fish caught	Number of rare species[a]	Observed species richness	Jacknife 2 richness estimate	Michaelis–Menten richness estimate
LWV1	852	2	9	10.8	9.7
LWV2	889	7	11	14.0	16.0
LWV3	921	1	6	6.0	6.4
LWV4	1,541	3	10	12.9	9.7
SWV1	18	1	3	4.6	4.3
SWV2	1,693	5	8	10.8	8.5
SWV3	749	0	5	5.0	5.6
SWV4	274	0	5	5.0	5.5
LCM1	627	1	6	7.8	5.8
LCM2	2,580	2	10	10.0	10.3
LCM3	786	1	5	6.8	5.0
LCM4	2,556	1	9	10.8	9.0
SCM1	19	0	2	2.0	2.1
SCM2	221	0	2	2.0	2.0
SCM3	121	0	2	2.0	2.1

[a] Species with relative abundance <1%.

number of fish caught (18–2,580) across the reaches. For 13 of the 15 reaches, the estimators of true species richness were within 2 species of the observed number. Thus, we believe that the distance study sampling captured almost all of the species present in most reaches.

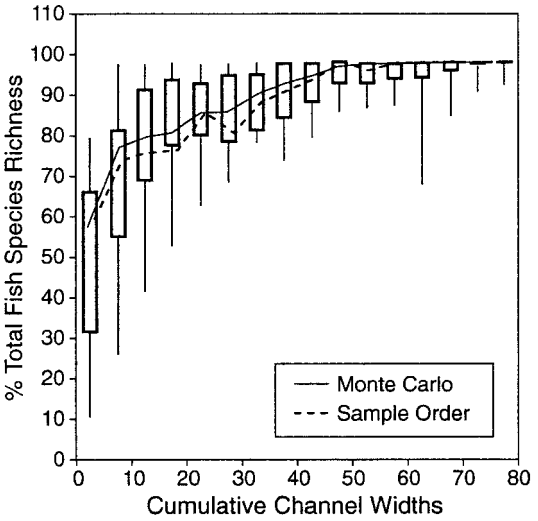

FIGURE 1.—Percent species richness versus cumulative channel width, averaged for 15 study reaches in western Oregon streams by sample order (dashed line) and Monte Carlo analysis (solid line). For graphical presentation, the cumulative channel widths are aggregated into classes of five channel widths (0−5, 6−10, and so forth). In the Monte Carlo results, the line connects the medians, the boxes show the interquartile ranges, and the whiskers show the minimum and maximum values within classes. For clarity, the sample order line connects the class means without showing the variances.

Species accumulation curves from the Monte Carlo and sample order analyses appeared to approach asymptotes near 40 cumulative channel widths (Figure 1). To compare results across reaches, we expressed cumulative species richness as a percentage of the total species caught at each reach. Virtually all mean Monte Carlo composites captured more than 90% of the species in 40–50 channel widths of sampling. There was virtually no difference in the accumulation curves between the Monte Carlo analysis and the sample order analysis, indicating that the initial starting point for reach sampling had little effect in this study.

Habitat unit IBI scores were expressed as a percentage of the final IBI score calculated for the entire reach. Thus, scores greater than 100% indicate an individual composite IBI that is greater than that calculated using all the data. With all reaches combined, IBI scores for less than 10 channel widths were typically 60–80% of the final IBI score with a very wide range, but they approached 100% of the final IBI score, with an interquartile range of 5 IBI units, by 40 channel widths (Figure 2).

Sampling Intensity

The rapid one-pass protocol occasionally missed rare species but yielded IBI scores and percent abundances similar to those from the intensive three-pass protocol (Figure 3). Chi-square tests of

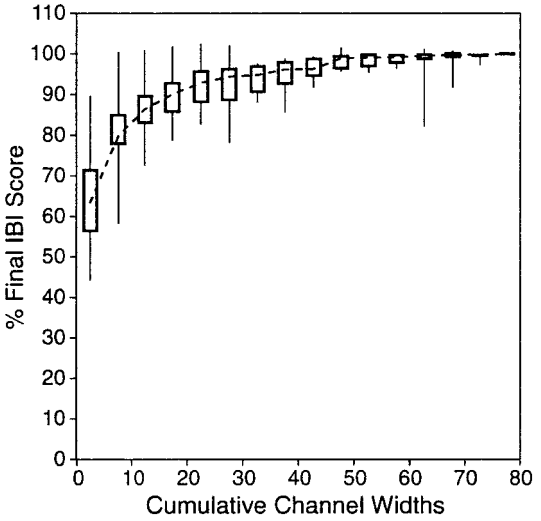

FIGURE 2.—Percent total index of biotic integrity score versus cumulative channel width, averaged across eight Willamette Valley reaches by habitat unit Monte Carlo analysis. See Figure 1 for additional details.

the independence of proportionate abundance between passes exhibited mixed results. In two of the three Willamette Valley streams, we found statistically significant ($P < 0.05$) differences between fish assemblages estimated from the rapid pass and successive passes. These differences were due largely to differences in the observed proportions of reticulate sculpin and redside shiner in LWV21 and yellow bullhead in LWV22. In LWV23, we saw no statistically significant difference between the rapid and intensive results. The results of the rapid one-pass protocol also differed significantly ($P < 0.05$) from those of more intensive passes in the Cascade Mountain stream (LCM4) due to differing proportions of young-of-the-year rainbow trout and mottled sculpin. Relative to the intensive three-pass sampling, the rapid one-pass protocol underestimated observed species richness by five species in one reach and by one species in another reach and produced identical species counts in the other two reaches (Table 3). In Willamette Valley reaches, the rapid one-pass and three-pass sampling yielded IBI scores within 2–7 points of each other (out of a possible 100; Table 3).

The rapid one-pass method produced estimates of the number of salmonids, cottids, and dace individuals that were an order of magnitude lower than the LTER population estimates determined from 10 times as much sampling effort from 1992 to 1996 at LCM4 (Figure 4). However, the percent abundance results were similar between the two methods, and the same annual patterns in abundance and percent abundance were evident in both curves. For example, both the rapid one-pass and population estimates yielded U-shaped dace curves and W-shaped catostomid curves over the 5 years. Repeat visits showed that estimates of percent abundance made with the rapid one-pass method were within 0–10% of each other within a year, though this is an insignificant evaluation.

Discussion

Sampling Distance

The median sampling lengths that we report for collecting all observed species (40 channel widths) are similar to those determined by Lyons (1992: 5–49), Angermeier and Smogor (1995:67–82), Paller (1995:35–158), and Patton et al. (2000:14–50). Each of these studies used a different analysis to estimate the length needed to sample species at a reach. We estimated the distance for adequate sampling (expressed in multiples of wetted channel widths) for each reach from cumulative samples and Monte Carlo simulations of habitat units. Lyons (1992) used a regression curve to fit his observed data, Angermeier and Smogor (1995) used Monte Carlo simulation with replacement, and Paller (1995) and Patton et al. (2000) used simulation without replacement.

For western Oregon reaches more than 4 m wide, we suggest sampling 40 channel widths for fish richness and percent abundance measures because 90% of observed species were captured within this distance at a set of 15 markedly different, randomly selected reaches. These recommended sampling distances are often insufficient to capture rare species (those comprising <1% of individuals captured) at a reach. While patchy species may be sampled by distributing sampling effort throughout a given area, an adequate sample for rare species may require collecting more individual fish. Sampling efficiency (which was 10%, based on the LCM4 comparisons) may be low enough in some cases to exaggerate species discontinuity and increase the length needed to capture species. However, our analysis of multiple reach passes indicated that the apparent habitat unit occupancy of species did not change with increased sampling intensity (data not shown). Nonetheless, if one wants to estimate true species

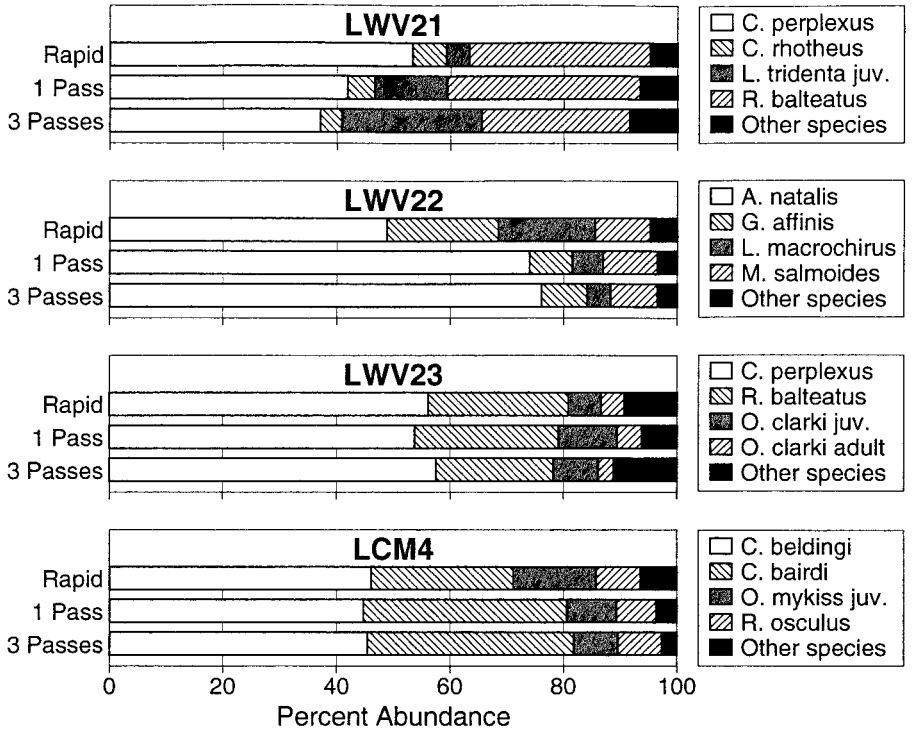

FIGURE 3.—Percent abundance of fish in assemblages in three intensively studied Willamette Valley reaches (LWV21–LWV23) and one Cascade Mountain reach (LCM4), as determined by rapid one-pass and intensive one- and three-pass surveys. Commonly found species were as follows: reticulate sculpin *Cottus perplexus*, torrent sculpin *C. rhotheus*, Pacific lamprey *Lampetra tridentata*, redside shiner *Richardsonius balteatus*, yellow bullhead *Ameiurus natalis*, mosquitofish *Gambusia affinis*, bluegill *Lepomis macrochirus*, largemouth bass *Micropterus salmoides*, cutthroat trout *Oncorhynchus clarki*, Paiute sculpin *C. beldingi*, mottled sculpin *C. bairdi*, rainbow trout *O. mykiss*, and speckled dace *Rhynichthys osculus*.

richness in the local species pool, 67–457 channel widths may be necessary for western Oregon streams (Cao et al. 2001). Though we do not suggest excluding rare species from all analyses, we believe that it is prudent to minimize their importance in large-scale regional assessments of stream fish assemblages, such as those of national and statewide monitoring programs. If reaches are too distant to sample more than one per day, a doubling of effort to capture rare species translates to halv-

TABLE 3.—Number of species and fish captured and index of biotic integrity (IBI) scores (Willamette Valley only) as determined by the rapid one-pass method and intensive one-, two-, and three-pass accumulated sampling in four Oregon stream reaches, each 40 channel widths long.

Site	Metric	Rapid pass	Intensive passes		
			1	1 + 2	1 + 2 + 3
LWV21	Species richness	9	13	14	14
	Fish caught	383	689	1,194	1,522
	IBI score	76	81	83	83
LWV22	Species richness	7	7	7	7
	Fish caught	127	265	385	447
	IBI score	11	13	12	13
LWV23	Species richness	10	9	10	10
	Fish caught	187	312	449	536
	IBI score	75	74	76	77
LCM4	Species richness	8	9	9	9
	Fish caught	195	1,736	2,378	2,460

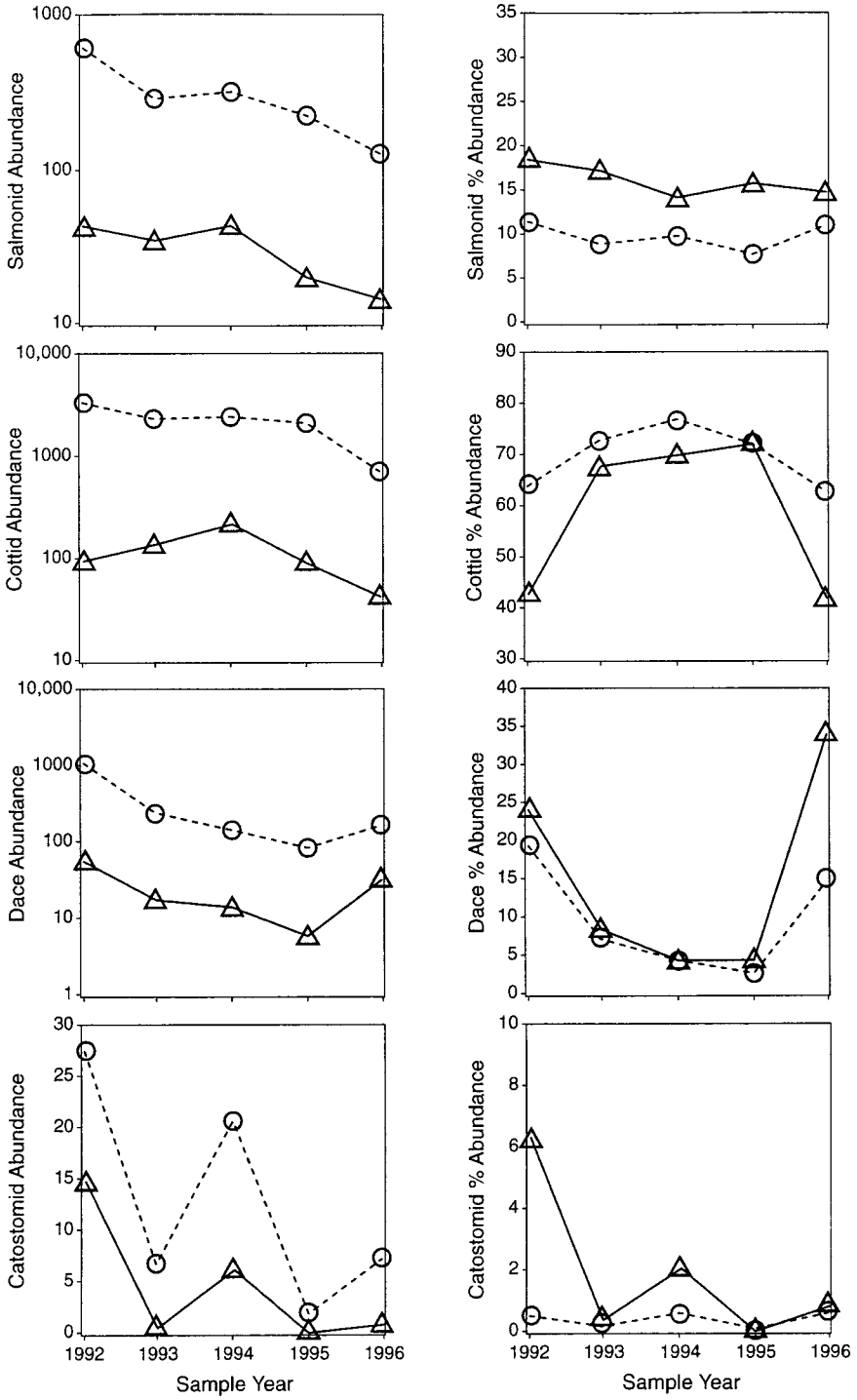

FIGURE 4.—Comparison of the absolute and percent abundances of four fish families in Lookout Creek (LCM4) from 1992 to 1996, as determined by rapid one-pass surveys (triangles and solid lines) and intensive three-pass surveys (circles and dashed lines).

ing the number of reaches sampled without doubling the information.

Sampling Intensity

A rapid one-pass protocol inconsistently detected the presence of rare species. When monitoring the change in fish assemblages through time or the differences among reaches, it may be impractical to reduce the uncertainty in sampling rare species. The rapid one-pass protocol did not consistently capture cryptic and vagile species, perhaps because it did not allot an adequate amount of time to sampling microhabitats. Another way to ensure capturing rare species is to increase the number of fish collected by increasing sampling efficiency regardless of sampling distance.

Our rapid one-pass protocol spread a fixed sampling duration over a large reach. Matthews (1990) concluded that sample adequacy is increased more by increasing the number of sampling locations than by increasing the number of collections per location. Similarly, Paller (1995) found that single-pass estimates of species richness from larger areas are as effective as seven-pass estimates. However, Pusey et al. (1998) reported that single-pass downstream electrofishing of reaches less than 40 m long poorly estimated relative abundances and species richness (but this is a shorter distance than our minimum recommended distance). The results from the rapid one-pass protocol were most similar to those of the intensive three-pass efforts in Cascade Mountain reaches with simple fish assemblage structures. When reaches are difficult to sample or assemblages are diverse, precision can be improved by increasing sampling intensity. Also, experienced field crews are essential for capturing species that are cryptic and hard to capture. Alternatively, more general metrics or indices such as IBI could be used to describe the fish assemblage (Figure 2; Table 3; Yoder and Smith 1998). The observed 2–7 point difference in IBI scores is considered insignificant, as it is similar to the difference in IBI scores commonly seen in repeat visits to the same reach using the rapid one-pass protocol (Hughes et al. 1998).

Percent abundances are often used to compare fish assemblages across reaches or through time (Rahel 1990). A major assumption in such studies is that the capture efficiency of each species does not differ substantially over time or among reaches. In our study, we occasionally observed differences in our ability to collect the same fish species in the same and different reaches. Evidence indicates that capture efficiencies vary by species (Larimore 1961), habitat, and sampling method (Bayley and Dowling 1993; Bayley and Peterson 2001). When assessing fish assemblages, we believe that it is prudent to evaluate routine methods through comparisons with more intensive methods to quantify capture efficiencies. In addition, there is a clear need to better understand the mechanisms causing variation in capture efficiencies.

In conclusion, it is important to assess spatial sampling sufficiency and sampling intensity in investigations of fish assemblages. We need to employ sampling methods that allow us to accurately and precisely assess fish assemblages and the stream ecosystems they represent. Our recommendation of minimum sampling length is based on empirical observations of 15 representative wadeable stream reaches in two ecoregions. Reach lengths of at least 40 channel widths in large wadeable streams and at least 150 m in small wadeable streams were sufficient in these two ecoregions to yield accurate and precise estimates of the richness and percent abundance of common fish species (proportionate abundances $>1\%$). At least for western Oregon streams, we recommend those sampling distances for assessing the status and trends in fish assemblage integrity. Our findings may not apply elsewhere, especially if sampling methods, habitats, fish faunas, and research objectives differ. However, our conclusions regarding adequate sample distances are consistent with those of other researchers in North America, suggesting widespread applicability.

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